PROGRESS IN TEA BREEDING

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Introduction

Tea was first introduced into Sri Lanka in 1839 when seeds were imported from Assam and planted in the Botanical Gardens at Peradeniya. The first commercial planting of tea commenced in 1867 when coffee was the mainstay of the Island's economy. With the advent of the Coffee Rust leaf disease, caused by the fungus *Hemileia vastatrix,* which spread rapidly and ravaged the coffee industry in 1870, tea was successfully grown and within a short period replaced coffee.

Tea presently covers an area of about 242,820 hectares, ranging from almost sea level to about 1,980 metres (Fig. 1) giving about 204 million kg of made tea per year. This contributes

Fig. 1. Tea growing areas of Sri Lanka

about 60% of the foreign exchange earnings of Sri Lanka. Sri Lanka ranks as one of the largest exporters of tea in the world. Over 85% of the total area of tea is presently under seedlings of highly mixed jat** and only about 12–15% are under clones selected for high yields and other desirable attributes. Much of the seedling tea is about 60–80 years old and some areas are no longer considered agriculturally productive. Originally the yield of seedling tea was around

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** Jat is a term only roughly corresponding to variety. Jats refer to the area from which a given seed supply originates and most jats consist of a large assortment of hybrids. High jat refers to the large-leafed Assam type of plant and low jat to the small-leafed China type of plant.

600 kg made tea per hectare per year but rose to about 800 kg with improved cultural practices. The Island's average yield at present is under 1,000 kg mt/ha/year. The yield of clonal tea in the higher elevations is around 2,500 kg mt/ha/year while in the lower elevations yields of 5,000-6,000 kg mt/ha/year are common. The highest yield recorded for a clone has been 8,000 kg mt/ha/year in the lower elevations. Thus, there is ample scope for improving tea yields appreciably by the introduction of superior clones. In view of this, the Government introduced a Tea Replanting Subsidy Scheme in November, 1958 to accelerate the rate of replanting.

Initially there were over 200 approved clones but only about 40 were being used for replanting as the majority did not perform well. Of these only about 10–15 are popularly used and over 95% of the replanted clones represent the TRI selections while the rest constitute estate selections. Tea in Sri Lanka is grown under widely varying soil and climatic conditions with different pest and disease problems and as such all clones are not suited for planting in all areas. The available clones have now been carefully evaluated for quality and their resistance to pests and diseases and clones suitable for the different areas have been recommended. Nevertheless the number of superior clones available is small and there is an urgent need for a greater number of high yielding clones possessing desirable characteristics (Tables 1 and 2).

Tea probably originated somewhere in Central Asia, 60°N or still further, from where it spread through secondary centres to the different regions of the world (Kingdon-Ward, 1950). The origin of the cultivated tea is in doubt because of the inability to trace the ancestry to a true wild population. According to the most recent classification (Barua, 1965) there are three kinds of cultivated teas indigenous to the three different geographical regions of South East

Table 1. Character ratings of some clones

Clones	Rooting	Yield	Quality	Blister	Eelworm	Drought	S.H.B.	Phomopsis
TRI 777	B	B	1	B	C	A	A	A
TRI 2023	A	A	3	C	C	B	A	A
TRI 2024	A	A	3	A	C	C	C	C
TRI 2025	A	A	4	B	B	A	C	A
TRI 2026	A	A	5		C	A	C	A
TRI 2027	A	A	3	C	C	A	C	B
TRI 2043	A	A	5	A	C	B	B	
TRI 2142	C	B	1	A	A	B		
DG 39	A	A			C	A	A	
DN	A	A	4	C	B	A	A	
DT 1	A	A	1	C	B	A	C	A
DT 95	A	B	4		A	A		B
K 145	B	B	3	B	A	C	A	B
N 2	A	A	1	A	A	A		
B 275	A	A	3					
CY 9	A	B		B	B	A	B	

For rooting & yield	For pests, diseases & drought	For quality
A = Above average	A = Resistant	1 = Excellent quality
B = Average	B = Moderately resistant	2 = Good quality
C = Below average	C = Poor resistance	3 = Satisfactory quality
		4 = Little quality
		5 = Poor quality

Table 2. Some recommended clones in Sri Lanka

High-elevation	Mid-elevation		Low-elevation
	Wet Zone	Dry Zone	
TRI 2023	TRI 2023	TRI 2023	TRI 2023
TRI 2025	TRI 2025	TRI 2025	TRI 2025
TRI 2027	TRI 2021	TRI 2021	TRI 2026
TRI 62/1	DG 39	TRI 2026	TRI 2021
DT 1	DN	TRI 2027	TRI 2022
B 275	KEN 16/3	DG 3	TRI 2027
TRI 62/9	TRI 2151	DG 7	TRI 62/5
DN	MT 18	K 145	DG 3
TRI 3013	KP 204	B 275	DP 204
TRI 3014	MPA 1	TRI 62/5	MPA 1
CC 34	CY 9	TRI 62/9	TRI 62/6
HS/10A	TRI 62/5	DN	TRI 2043

Asia, viz., Assam, China and Indochina of which the first two are distinct species, *Camellia assamica* Masters and *Camellia sinensis* L., while the third form which is known as the "Southern" form or the "Cambod" type is regarded as a subspecies of the Assam plant and named *Camellia assamica* subsp. *lasiocalyx* Planch M.S. (Wight, 1962). A species of wild tea, *Camellia irrawadiensis* P.K. Barua, which does not contain caffeine like the cultivated tea, has also been described and is considered indigenous to upper Burma. Other species such as *C. taliensis, C. flava* (Pitard) Sealy, *C. petilotii* (Merrill) Sealy, *C. lutescens* Dyer, etc. have also been thought of as having contributed to hybrid tea populations. Chemical composition and the presence or absence of sclereids and other morphological characters have also been used to indicate the closeness of the relationship one species bears to another (Roberts, Wight and Wood, 1958). The commercially cultivated teas therefore, consist of natural hybrids of the three main types of cultivated teas and there is reason to believe that complex hybrids of these three kinds of tea and one or more of the wild species of Camellia occur in the cultivated tea populations (Barua, 1965; Sharma and Venkataramani, 1974). Seedling populations in Sri Lanka consist of hybrids ranging from one extreme to the other (Fig. 2).

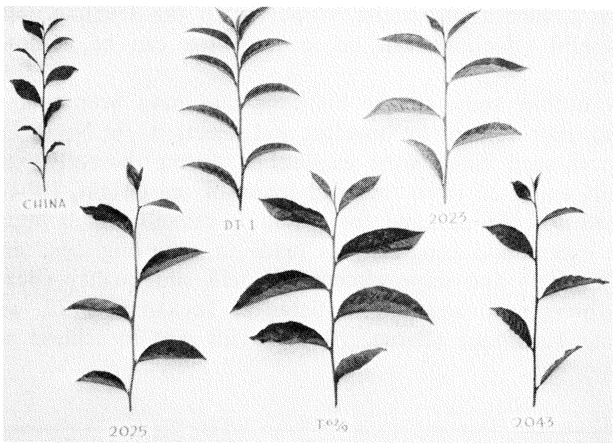

Fig. 2. Range of foliar characteristics in tea clones

Some information on the floral biology of tea might perhaps be useful in understanding the breeding behaviour of this crop and appreciating the problems of tea breeding. The largest number of flowers bloom during the morning when there is plenty of sunshine. Under Sri Lanka conditions, flowering occurs throughout the year but is irregularly distributed. Under high elevation conditions in Sri Lanka, the flowering intensity increases from October, reaching a peak in February. During the other months the number of flowers decreases. Different clones exhibit different intensities of flowering and fruit-set. Reliable crop of flowers can be expected generally after 6-8 years of free growth although flowers may be seen earlier in nursery plants, with viable pollen. The number of stamens per flower also differs in the different clones ranging from about 110 to over 365. The ovary has usually three locules and the style carries a trifid stigmatic head. Although flowers are produced in abundance in seed bearers, the percentage fruit-set is very low being about 2% under natural conditions and about 14% or higher up to about 60% in some artificial crosses. The stigmatic surface is receptive only for about 48 hours after anthesis and by the third day the corolla and stamens wither and fall off. Pollen grains germinate in 3-4 hours and can be stored in a viable condition for over three months. Viable pollen grains are heavy and not carried far by wind. Pollination is effected, in nature, largely by ants and small flies with a short flying range. Hence, seed baries* may not require far isolation as once suggested. Tea is almost completely self-sterile and requires cross pollination for the satisfactory setting of viable seed. The nature of self-incompatibility was shown to be due to the arrest of pollen tube growth in the selfed styles accompanied by larger amounts of callose deposition at their tips (Tomo, Fuchinone and Yamane, 1956; Rogers, 1975). The time from anthesis to mature fruit development is about 8-12 months. Tea seeds lose viability fairly rapidly and must be used at the earliest opportunity if satisfactory germination is to be achieved. Tea seeds have been successfully stored for over a period of 10 months.

Breeding of tea

In view of the wide distribution of tea in both hemispheres and the outbreeding nature of the crop, tea populations over the years have become extremely heterozygous. It has become difficult to identify a population in the wild state. A tea breeding programme, like those of many other perennial tree crops, is necessarily a very long term project because of the long time required for the completion of the life cycle. Improvements by breeding have, therefore, been slow. Several generations may be required before a useful progeny can be identified and adequately tested. Furthermore, since tea is grown under very diverse conditions with specific problems, the requirements also vary greatly. A breeding programme has, therefore, to take into account those specific requirements (Richards, 1966; Bezbaruah, 1968; Visser, 1969). Nevertheless, there is a wealth of genetic variability in the seedling populations that already exist from which useful selections can be made which can be commercially exploited by vegetative propagation.

I shall briefly outline some of the methods that have been used in North East India and Sri Lanka for tea improvement by breeding and selection. In North East India, commercial seed gardens known as seed baries were established during the early phase of tea cultivation from seeds and plants collected from the wild tracts of tea (Wight, 1961). Mass selection was the method practiced for a long time for tea improvement which improved the indigenous Assam tea to some extent and progress was made in achieving some degree of homogeneity in morphological characters and improvement of yield and quality (Bezbaruah, 1968). The objective of the tea breeding programme, initiated at Tocklai in 1939, was to improve the tea by the Line Breeding Technique (Barua, 1963). This was to achieve uniformity within and

* Seed bari: An orchard of tea trees grown for the purpose of obtaining seeds.

diversity between types of progenies from which selections could be made for the different regions. Seeds are initially produced by artificial pollination between selected pairs of bushes and the seedling progenies are planted out in replicated plots along with a popular commercial jat for comparison. The two bushes, whose seedling progeny shows promise, are then vegetatively propagated and planted as generative clones in alternate rows, in isolated seed gardens, to produce seed by natural cross pollination. The number of plants of each clone need not be the same if one is a better seed producer than the other. The bi-clonal seedling progenies are then tested at Tocklai and other districts. The final selection of each pair of generative clones is made on the performance of their bi-clonal seedling progeny. The testing for various attributes of one generation of bi-clonal seedlings may take seven years or more and to effect reasonable improvements sometimes it may take as many as three generations. It has been suggested that the use of a "combiner" clone which transmits its morphological features to its progeny, after crossing with another clone, merits consideration if uniformity can be achieved (Wight, 1961). The practicability of this has yet to be proved. Pubescence of the flush was thought to be related to quality but it is not generally so. Nevertheless, this character has been shown to produce "tippy" teas in orthodox manufacture. Poly-clonal seed gardens have also been tried out but the results are more unpredictable than those from bi-clonal progenies. Bi-clonal seedling progenies are preferred but the testing takes a long time.

In Sri Lanka, in the early years seed was obtained indiscriminately from various sources. It was soon realised that seed obtained from certain sources produced more vigorous seedlings than others. Later introductions of seed were, therefore, of a better type which gave more vigorous seedlings with a higher yield. It was only in the late thirties, with the perfectioning of the vegetative propagation method by single-node cuttings that some conscious effort was made towards improvement by selection and the establishment of clones.

A breeding programme was initiated at the Institute in 1961. In the period 1961-1965, extensive clonal testing trials were laid out as replicated Randomized Blocks in the four main planting districts with previously selected TRI and estate clones. The most popular TRI clones viz. the 2020-series, are all selections made at the TRI from seedlings raised in 1937 from a single open pollinated seed bearer (Richards, 1965). The estates have also made some useful selections which are noted for high quality and resistance to drought and eelworm. The above trials formed the basis for the recommendation of clones suitable for the different districts. In the period 1966-1975, new selections from open pollinated seedlings and from artificial crosses of popular TRI and estate clones with desirable attributes eg. TRI 2024, TRI 2025, TRI 1114, TRI 777, DT 1, TC 9, DN etc. have been made and planted out in clonal trials for evaluation. The more recent trials have employed the Lattice design rather than the Randomized Blocks as the former is more suitable for testing large numbers of clones and requires less space. The 62-series of clones, also obtained from open pollinated seed in October, 1958 have shown promise in the yield trials and have been recommended to estates for experimental planting. The selections designated as the 3000-series have given high yields and a few are as good, if not better, than the 2020-series of clones. The results of artificial pollination work have also enabled to identify certain clones as good "combiner" clones eg. TRI 114, TRI 2024 etc. and others as poor "combiners" eg. DT 1, DG 39 etc. Several hundred seedlings from open pollinated seeds of TRI and estate clones and from artificial crosses are also under field observations and preliminary tests for quality, eelworm tolerance etc. are being undertaken. Bi-clonal seedlings of TRI 2023 and TRI 2026 have also been tested. Majority of these are less vigorous than the parental types but appear to be more vigorous and uniform with a high percentage of large leaved types compared with seedlings obtained from unselected seed.

The tea breeding programme as envisaged has a two-fold objective: 1. The production of potential "combiner" generative clones which give rise to vigorous and uniform seedling progenies with desirable characteristics. 2. The selection of vegetative clones from the seedling progenies for commercial propagation. Seedling populations available at present are extremely heterozygous with a high percentage of small-leaved types, less likely to give a high yield. Uniformity in a population is desirable but, due to the absence of homozygous stocks, obtaining seedlings with morphological uniformity appears to be impracticable at present. Clones selected for breeding are probably likely to be heterozygous. Therefore, the production of bi-clonal or even poly-clonal seed appears to be the only practical way at present of achieving some degree of homozygosity from which further selections can be made to obtain superior clones.

Selection

Selection as a basis for tea improvement has paid handsome dividends in the early years when rapid strides were made in tea yields. From a meagre 600-800 kg mt/ha/year from seedling tea, increases of the order of 3,000 and 6,000 kg mt/ha/year are now common with clones in the high-elevation and low-elevation districts respectively. The origin of some of the popular clones has been traced by Richards (1965). The extreme variability of seedling populations for yield and other characters is well known. This affords a good opportunity for selection work which is being intensified. The selection procedure and the important characteristics to look for have been outlined by several workers (Kehl, 1950; Barua, 1964; Richards, 1966; Visser, 1969; Venkataramani, 1970). The simultaneous selection for all the desirable characters is difficult and impracticable, in addition to being costly and time consuming. Some of these characters need not necessarily be associated with the yield potential of clones (Green, 1971). Wight (1958) estimates the chances of obtaining a superior clone as 1 in 40,000 from field populations of seedlings in North East India. Present methods of selection for high yields are, therefore, largely empirical, slow and laborious. Correlations of various morphological and physiological characters of seedling teas with the yield of clones derived from them have, in most instances, been weak and of limited value (Wellensiek, 1940). Both Tubbs (1938; 1939) and Eden (1941) recommended the yield of seedling bushes as a criterion for selecting high yielding clones but Tubbs later (1946) warned that environmental and inherited contributions to yield could not normally be distinguished. Selections in fields of immature seedlings and in seedling nurseries have long been accepted as alternatives to the selection of mature seedling bushes. Height, girth at collar, root weight and branching angle of young seedlings in the nursery were correlated with the size and yields of the same plants when mature, but not with the rates of growth in the nursery or the yields at maturity, in the plants derived from these seedlings by vegetative propagation (Green, 1971). The author concludes that the above criteria and the use of the "Phloem Index" are of limited value in selection under normal field conditions. Assessments of growth and vigour of young plants, leaf and bush size and growth habit of mature seedlings still remain the only bases for selection of clones. The above are useful in reducing base populations to manageable numbers for yield trials which at present appear to be indispensable.

Propagation

The vegetative propagation technique is now standard practice and has been discussed adequately by several workers (Kehl, 1950; Wight, 1955; Visser, 1961; Green, 1964; Richards, 1966).

Clonal testing

The performance of the provisionally selected clones has to be tested before final selection. In the early clonal testing trials it was found that a reliable indication of the yields could be obtained only in the second year of the second pruning cycle. This means that at least six years would be required before the clone can be adequately evaluated. This is expensive, time consuming and requires a lot of experimental land. The yield of several clones was shown to be correlated with the increases in height and weight of young plants at 8-12 months of age and also with the rate of increase in height of the plucking table following pruning (Kulasegaram, 1969). Recently, the yield of several clones in different districts over a period of seven years was found to be strongly correlated with the yield in the immature stages, particularly the first year yields (Sebastiampillai and Solomon, 1976). This would considerably reduce the time lag between selection and the release of clones to the industry (Fig. 3, 4 and 5).

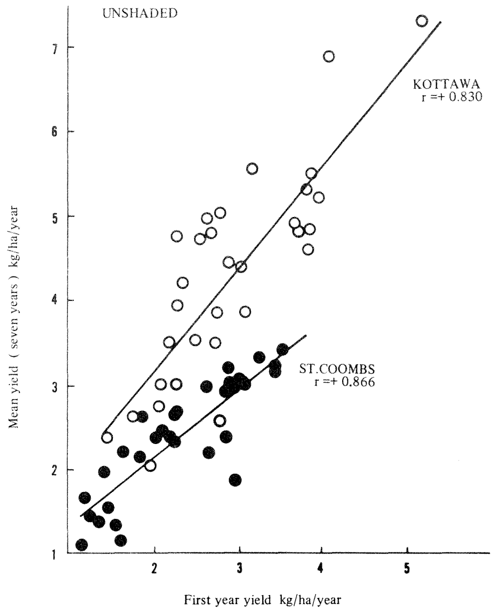

Fig. 3. Relationship between the first year yield and the mean yield of seven years in unshaded tea in high (St. Coombs) and low (Kottawa) elevations

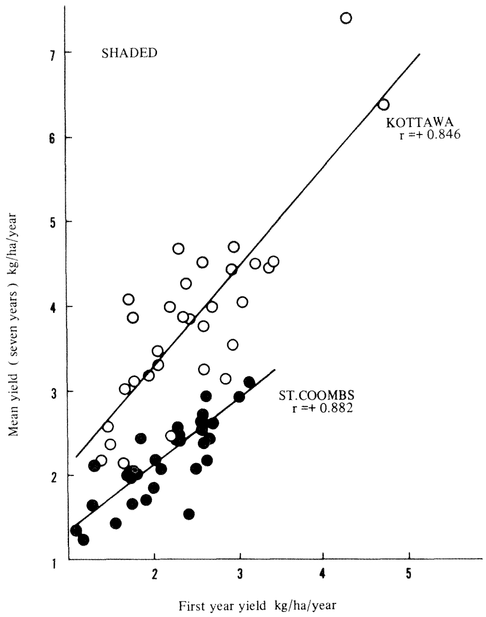

Fig. 4. Relationship between the first year yield and the mean yield of seven years in tea under shade in high (St. Coombs) and low (Kottawa) elevations

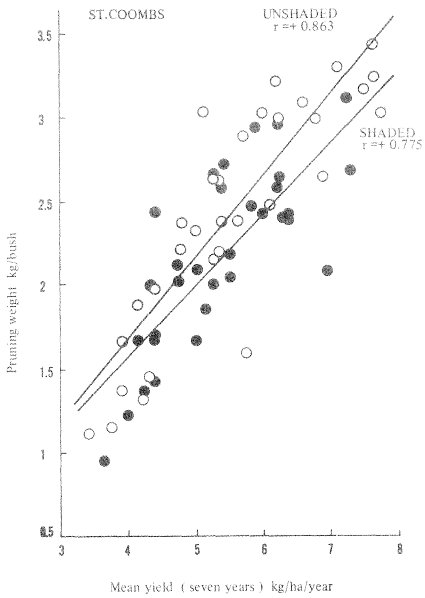

Fig. 5. **Relationship between the pruning weight and the mean yield of seven years in high elevation shaded and unshaded tea**

Cytology

Cytological investigations in all the cultivated tea varieties showed a remarkably constant chromosome number of 2n = 30, except for a few natural triploids (3n = 45). Natural polyploids, are not commonly found in cultivated teas although common in ornamental Camellias grown for the large size of their flowers (Longley and Tourje, 1959; Karasawa, 1932; Simura, 1935; Janaki Ammal, 1952; Bezbaruah, 1970; Sebastiampillai, 1976).

Inheritance

Genetical investigations in tea are scanty. The number of calcium oxalate crystals in the phloem of the leaf petiole (Phloem Index) and the density and length of hairs on the flush are reported to be quantitatively inherited (Bezbaruah, 1974). In intervarietal crosses involving Assam and China jats of tea, partial dominance of the China jat was observed in the inheritance of leaf size. The quality of made tea of the F_1 hybrids generally approached mid-parental values and no dominance or interaction were observed. Furthermore, no difference was observed in yield and quality of reciprocal hybrids from crosses between morphologically different varieties. Analysis of inheritance of yield in bi-clonal crosses of different ancestries showed positive correlation between mean yield of parents and progenies, which was absent when clones of related ancestries were used. Heterosis, in respect of yields, ranging from 21-85% over the mid-parental value was also observed in clonal crosses of different ancestries indicating that hybrid vigour could be exploited in increasing tea yields.

Interspecific hybridization

This has been demonstrated between the cultivated tea and the wild tea Wilson's Camellia, *C. irrawadiensis* which does not contain caffeine (Wight and Barua, 1957). The F_1 hybrids lacked quality but their extreme vigour suggests the possibility of their use for further breeding. A triploid hybrid has also been obtained from a cross between a tetraploid, *C. sinensis* (4n = 60) and a diploid, *C. japonica* L. (2n = 30) (Bezbaruah and Gogoi, 1972).

Mutation and ploidy

Attempts at inducing mutation by treatment of seeds and cuttings with mutagenic rays and colchicine have met with poor results (Amma, 1974; Katsuo, 1966). Sebastiampillai (1976) obtained tetraploid plants of five clones by treatment with colchicine (0.2-0.5%). If ploidy could be induced relatively easily, it could serve as an additional source of variation which may result in improved performance of existing diploid clones. A start was also made in developing a technique for the culture of anthers on artificial media in the hope of obtaining haploid plants which could prove useful in obtaining homozygous strains.

The occurrence of natural triploids has been reported. Tetraploids and aneuploids have been reported from progenies of natural triploids. Commercial exploitation of polyploids has not been reported except for the planting in South India of a natural triploid clone Sundaram (Venkataramani, 1969; Jayasuriya and Govindarajulu, 1971) which is a high yielding clone. Induced tetraploids of some popular TRI clones showed poor growth with narrower branching angles and gave lower yields compared with the corresponding diploid clones.

In conclusion, it will be noted that a tea improvement programme by breeding and selection is necessarily a very long-term project because of the outbreeding nature of the crop with a long life cycle and the absence of homozygous stocks. Nevertheless, the store of genetic variability that already exists provides us with a means of exploiting this variability by selection and vegetative propagation. Unfortunately the selection procedures available at present are subjective and there is an urgent need to make them more quantitative so that the results can be easily predicted. Progeny testing in the past has also taken a minimum of six years. Short-cuts in this procedure are being evolved which may result in the early release of clones for commercial planting. There is the hope that other aids such as tissue culture and genetic engineering procedures will be evolved to aid in tea improvement. The establishment of germplasm banks is an urgent need for preserving the genetic variability which the breeder may require for the future.

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Discussion

N. Yamada, Japan: Tea produced in Sri Lanka is world famous for its good quality under the name of Ceylon Tea. Could you tell us how you achieve such results?

Answer: Our main interest is to increase the yield of tea and also to develop a larger number of high yielding clones. The selection for quality receives a lower priority than that for yield. It is generally observed that the high-yielding clones are of average quality while the very good quality clones are generally average to poor yielders.

S. Amma, Japan: I am very much interested in individual plant selection. Would you please tell me how to select the individual plant initially?

Answer: Initial selection is on the basis of individual selection by eye judgment. The characters to look for have been obtained by several workers. It is difficult to select for all the characters at once. Furthermore, there are no quantitative criteria yet. I would like to suggest that initial selection be made on flush size and flush number as these mainly determine the final yield. Other characters could be accommodated subsequently. In this type of work, the experience acquired by the breeder is most important.

J. Soria, Costa Rica: From your statement in which you mentioned that there was no correlation between the early evaluation of the selected plant and its clonal progenies, it appears to me that environment factors are playing a large role in tea production variability. However, you could perhaps better evaluate heritability if you measured the variation within crosses or open pollinated progenies of the selected parents, as compared with that within clones.

Answer: Environment certainly plays an important role in tea production variability. However, we could evaluate heritability by measuring the variability in crosses of clones of different ancestries. We hope to embark on such studies in the near future. The expression of the genetic potential can be maximised when the testing is carried out in an environment without constraints to growth and yield.

K. Kawano, Japan: Is it necessary to pursue homozygosity in your selected clones?

Answer: No, but the availability of homozygous stocks may greatly aid in breeding work and produce quicker results.